Table 5-1. Hydrologic Data for the Biofiltration Swale

SAMPLE COLLECTION DATE	RAIN DATA			FLOW DATA		EFFECTIVE SWALE LENGTH
	Rain (inch)	Duration (hour)	Intensity (inch/hr)	Qmax (cfs)	Qavg (cfs)	
HYDROLOGIC DATA FOR THE 200 FOOT LONG SWALE						
June 20, 91	0.24	5.5	0.04	0.29	0.16	187'
July 15, 91	0.17	2.5	0.07	0.12	0.02	187'
July 24, 91	0.4	3	0.13	0.78	0.40	187'
August 9, 91	0.78	4	0.20	1.35	0.31	187'
Oct. 24, 91	0.67	7.25	0.09	0.61	0.21	187'
Oct. 31, 91	0.27	7.5	0.04	0.18	0.10	187'
HYDROLOGIC DATA FOR THE 100 FOOT LONG SWALE						
Nov. 17, 91	1.25	11.5 *	0.11	0.29	0.07	90'
Jan. 16, 92	0.18	3.5	0.05	0.09	0.03	90'
Jan. 23, 92	0.27	7	0.04	0.18	0.05	90'
March 27, 92	0.52	3	0.17	0.49	0.21	90'
April 16, 92	0.59	4	0.15	0.65	0.25	90'
April 29, 92	0.61	6	0.10	0.56	0.11	90'

Note: The hypothetical 2-year, 24-hour design storm would produce 1.5 inches of rainfall with a Qmax of 1.7 cfs.

Water Quality Data

Tables 5-2, 5-3, and 5-4 present the water quality data as well as the percent removals on a per storm basis. Data was validated (checked against key parameters such as holding times, matrix spike recovery, agreement of laboratory duplicates, closeness to detection limits, and field and chain of custody information) to assure accuracy of analysis. Procedures for data validation recommended by USEPA (Bleyler, 1988) were followed. Appendix E discusses the quality assurance aspects

Table 5-2. Water Quality Data for 200-Foot Swale Configuration

BIOFILTRATION SWALE 200-FOOT CONFIGURATION (Units: mg/L unless otherwise specified)

Date Collected:	IN 6/20/91		IN 7/15/91		IN 07/24/91		IN 08/09/91		IN 10/24/91		IN 10/31/91		n Value		Average	Standard Deviation
NO2 + NO3-N	0.21		0.64		0.47		0.31		0.23		0.25		6		0.35	0.17
Ortho-P	0.017	*	0.043		0.031		0.042		0.088		0.036	J	6		0.04	0.02
TP	0.092		0.33		0.34		0.095		0.23		0.11		6		0.20	0.12
BAP	0.071		0.088		0.131		0.058		0.072		0.015	*	6		0.07	0.04
TSS	18		51		180		110		190		19		6		94.67	77.61
Turbidity(NTU)	5.7		19		41		32		6.2		13		6		19.48	14.34
Hardness											16					
Total Cu (mg/L)	0.002	*	0.031		0.013		0.002	* <	0.002	* <	0.002	*	3	>	0.02	0.01
Total Pb (mg/L)	0.02	*	0.03	*	0.05	* <	0.02	*	0.01		0.006		5		0.02	0.02
Total Zn (mg/L)	0.068		0.25		0.21	<	0.071		0.05	J	0.038		6		0.11	0.09
Total Al (mg/L)	0.6		1.2		3		0.74		0.53		0.17		6		1.04	1.02
Total Fe (mg/L)	0.92		2.5		4.5		0.69		0.24		0.31		6		1.53	1.67
Fecal coliform (CFU/100 ml)			5/24/91		150		10400		300		1200	J	4		3012.50	4946.78
Oil & Grease	2.2	*	4.3		39	U			6.5	U	640	R	4		13.00	17.42
TPH	2.2	*	3.6		26	U			6.5	U	640	R	4		9.58	11.10

Date Collected:	OUT 6/20/91		OUT 07/15/91		OUT 7/24/91		OUT 8/09/91		OUT 10/24/91		OUT 10/31/91		n Value		Average	Standard Deviation
NO2 + NO3-N	0.21		2.1		1.2		0.57		0.31		0.21		6		0.77	0.75
Ortho-P	0.014	*	0.043		0.027		0.088		0.051		0.016	*J	6		0.04	0.03
TP	0.07		0.25		0.24		0.11		0.096		0.052		6		0.14	0.09
BAP	0.029		0.07		0.097		0.023		0.042	<	0.01	*	5	<	0.05	0.03
TSS	2	*	12		26		34		6		4	*	6		14.00	13.08
Turbidity	0.78		6.8		14		3		3.6		7.5		6		5.95	4.67
Hardness											17					
Total Cu (mg/L)	< 0.002	*	0.012		0.009	*	0.002	* <	0.002	* <	0.002	*	2	<	0.01	0.00
Total Pb (mg/L)	< 0.02	*	0.02	* <	0.02	* <	0.02	*	0.001	*	0.003	*	3	<	0.01	0.01
Total Zn (mg/L)	0.032		0.06		0.073	<	0.044		0.018	J	0.006	*	6		0.04	0.03
Total Al (mg/L)	0.18		0.4		0.76		0.44		0.08		0.01		6		0.31	0.28
Total Fe (mg/L)	0.21		0.57		0.99		0.28		0.05		0.13		6		0.37	0.35
Fecal coliform (CFU/100 ml)			5/24/91		431		12300		48		3100	J	4		3969.75	5717.00
Oil & Grease	< 1	* <	1	*	3	*U			4.6	U	230	R	2		3.80	1.13
TPH	< 1	* <	1	*	1.5	*U			4.6	U	180	R	2		3.05	2.19

BIOFILTRATION SWALE 200-FOOT CONFIGURATION PERCENT REMOVAL

Date Collected:	6/20/91		07/15/91		7/24/91		8/09/91		10/24/91		10/31/91		n Value		Average % Removal	Standard Deviation
NO2 + NO3-N	0		-228		-155		-84		-35		16		6		-81	86.87
Ortho-P	—	*	0		13		-110		42		56	J	5		0	58.34
TP	24		24		29		-16		58		53	*	6		29	24.06
BAP	59		20		26		60		42	>	33		6	>	40	15.31
TSS	89	*	76		86		69		97		79		6		83	8.99
Turbidity	86		64		66		91		42		42		6		65	18.97
Total Cu (mg/L)	—		61		31	*	—		—		—		2		46	15.26
Total Pb (mg/L)	—		—	>	60	*	—		90	*	50	*	3	>	67	17.00
Total Zn (mg/L)	53		76		65		38		64	J	84	*	6		63	14.99
Total Al (mg/L)	70		67		75		41		85		41		6		63	16.63
Total Fe (mg/L)	77		77		78		59		79		58		6		72	9.06
Fecal coliform (CFU/100 ml)			5/24/91		-187		-18		84		-158	J	4		-70	109.50
Oil & Grease	> 55	* >	77		92	*J					64	R	3	>	75	18.99
TPH	> 55	* >	72		94	*J					72	R	3	>	74	16.24

* Value computed with one or both obs <5X Detection Limit
J = value an estimate due to exceedance of QA criteria
R = Data unuseable
U = Data unreliable

Table 5-3. Water Quality Data for 100-Foot Swale Configuration

BIOFILTRATION SWALE 100-FOOT CONFIGURATION (Units are in mg/L unless otherwise specified)

Date Collected:	N 11/17/91		N 01/16/92		N 01/23/92		N 3/27/92		N 4/17/92		N 04/29/92		n Value	Average
NO2 + NO3-N	0.06		0.59		0.23		0.42	U	0.031	*	0.23		6	0.26
Ortho-P	—		< 0.005	*	< 0.005	*	0.007	*	0.022	*	< 0.005	*	3	0.01
TP	0.029		0.12		0.025	*	0.015	*	0.16		0.24		6	0.10
BAP	0.008	*	0.026		0.03		0.012	*	0.19		< 0.005	*	6	0.05
TSS	57		91		130		150		190		150	J	6	128.00
Turbidity(NTU)	8.7		47		51		36	U	6.6		49		6	33.05
Hardness														
Total Cu (mg/L)	0.005	*	0.008		0.006	J*	0.007	J	0.012		0.014		6	0.01
Total Pb (mg/L)	0.002	*	0.019		0.044	J*	0.013		0.041		0.018		6	0.02
Total Zn (mg/L)	0.016		0.11		0.096		0.047		0.13		0.14		6	0.09
Total Al (mg/L)	0.17	J	2.6		1.3		1.7	U	3.2		2.6		6	1.93
Total Fe (mg/L)	0.08		3.6		1.5		1.9		3.1		3.5		6	2.28
Fecal coliform (CFU/100 ml)	32	J	18		162		283		94		231		6	136.67
Oil & Grease	—		1.5	*	2.9	*							2	
TPH	—		< 1	*	< 1	*							0	

Date Collected:	OUT 11/17/91		OUT 01/16/92		OUT 01/23/92		OUT 3/27/92		OUT 04/17/92		OUT 04/29/92		n Value	Average
NO2 + NO3-N	0.06		0.74		0.24		0.49	U	0.059		0.25		6	0.31
Ortho-P	—		< 0.005	*	< 0.005	*	0.005	*	0.013	*	0.035		3	0.01
TP	0.015	*	0.031		0.015	*	< 0.005	*	0.13		0.18		5	0.06
BAP	0.003	*	0.006	*	0.006	*	< 0.005	*	0.033		0.045		5	0.02
TSS	4	*	7		9		140		50		150	J	6	60.00
Turbidity	3.6		13		16		17	R	4.9		10		6	10.75
Hardness														
Total Cu (mg/L)	0.005	*	0.003	*	0.002	*J	0.015		0.009		0.018		6	0.01
Total Pb (mg/L)	0.001	*	< 0.001	*	0.005	*J	0.029		0.024		0.023		5	0.01
Total Zn (mg/L)	0.022		0.049		0.013		0.078		0.082		0.11		6	0.06
Total Al (mg/L)	0.07	J	0.6		0.29		3.7	R	2		3.5		6	1.69
Total Fe (mg/L)	0.05		0.53		0.38		4.6		2.1		5.6		6	2.21
Fecal coliform (CFU/100 ml)	6000	J	8		44		100		150		83		6	1064.17
Oil & Grease			< 1	*	< 1	*							0	
TPH			< 1	*	< 1	*							0	

100-FOOT CONFIGURATION PERCENT REMOVAL

Date Collected:	11/17/91		01/16/92		01/23/92		03/27/92		4/17/92		4/29/92		n Value	Average % Removal	Std Dev	Adjusted Avg (1)	
NO2 + NO3-N	0.00		-25.42		-4.35		-16.67	U	-90.32	*	-8.70		6	-24	34	-27	
Ortho P	—		—		—		—		40.91	*	-600.00	*	2	-280	453	41	(2)
TP	48.28		74.17		40.00	*	> 66.67	*	18.75		25.00		6	45	22	50	
BAP	62.50		76.92	*	80.00		> 58.33	*	82.63		-800.00	*	6	-73	356	72	
TSS	92.98		92.31		93.08		6.67		73.68		0.00	J	6	60	44	72	
Turbidity	58.62		72.34		68.63		52.78	U	25.76		79.59		6	60	19	56	
Hardness																	
Total Cu (mg/L)	—		62.50		66.67	*	-114.29	J	25.00		-28.57		5	2	76	10	
Total Pb (mg/L)	—	>	94.74	*	88.64	*	-123.08		41.46		-27.78		5	15	91	25	
Total Zn (mg/L)	-37.50		55.45		86.46		-65.96		36.92		21.43		6	16	58	15	
Total Al (mg/L)	58.82		76.92		77.69		-117.65	U	37.50		-34.62		6	16	78	27	
Total Fe (mg/L)	37.50		85.28		74.67		-142.11		32.26		-60.00		6	5	88	18	
Fecal coliform (CFU/100 ml)			55.56		72.84		64.66		-59.57		64.07		5	40	56	64	(3)
Oil & Grease	—	>	33.33	*	> 65.52	*							2	49	23	49	
TPH	—		—		—												

* Value computed with one or both obs <5X Detection Limit
R = Data unreliable: blank value above DL
J = Value an estimate due to exceedance of QA criteria

(1) Excluding the 4/29 Storm data
(2) 4/17 data only
(3) also excluding 11/17

Table 5-4. Biofiltration Dissolved Metal Removals for 200- and 100-Foot Swales

200-FOOT CONFIGURATION DISSOLVED METALS

Date Collected:	IN 7/15/91		IN 7/20/91		IN 07/24/91		IN 08/09/91		IN 10/24/91		IN 10/31/91	
Cu (mg/L)	0.021		0.002 *		0.01		0.007 *		0.002 *		0.004 *	
Pb (mg/L)	< 0.02 *		< 0.02 *		< 0.02 *		< 0.02 *		< 0.001 *		< 0.001 *	
Zn (mg/L)	0.15		0.048		0.11		0.023		0.021 J		0.015	
Al (mg/L)	0.19		< 0.01 *		0.22		0.37		< 0.01 *		0.02 *	
Fe (mg/L)	0.29		< 0.01 *		0.13		0.01 *		0.02 *		0.03 *	
	OUT		OUT		OUT		OUT		OUT		OUT	
Cu (mg/L)	0.012		< 0.002 *		0.013		< 0.002 *		0.004 *		0.005	
Pb (mg/L)	< 0.02 *		< 0.02 *		< 0.02 *		< 0.02 *		< 0.001 *		< 0.001 *	
Zn (mg/L)	0.072		0.01		0.055		0.058		0.007 *J		< 0.002 *	
Al (mg/L)	0.15		< 0.01 *		0.02 *		0.32		< 0.01 *		0.05 *	
Fe (mg/L)	0.33		< 0.01 *		0.12		0.31		0.02 *		0.05	

	State Water Quality Standard *	
	(Acute)	(Chronic)
Cu (mg/L)	0.003	0.0026
Pb (mg/L)	0.0085	0.0003
Zn (mg/L)	0.0261	0.0236
Al (mg/L)		
Fe (mg/L)		

*(with hardness = 17 mg/L)

Percent dissolved (Dissolved/Total *100) (INFLOW)													Average
Cu (mg/L)	68%		100% *		77%		—		—		—		82%
Pb (mg/L)	< 67%		—		< 40% *		—		< 10% *		< 17% *		33%
Zn (mg/L)	60%		71%		52%		32%		42% J		39%		49%
Al (mg/L)	16%		< 2% *		7%		50%		< 2% *		12% *		15%
Fe (mg/L)	12%		< 1% *		3%		1%		8% *		10% *		6%

Percent removal of dissolved metals											n Value	Avg	
Cu (mg/L)	42.86		—		-30.00	>	71.43 *		—		-25.00 *	4	-7	
Pb (mg/L)	—		—		—		—		—		—	0	—	
Zn (mg/L)	52.00		79.17		50.00		-152.17		66.67	>	86.67	6	30	
Al (mg/L)	21.05		—		90.91		13.51		—		-150.00 *	4	-4	
Fe (mg/L)	-13.79		—		7.69		-3000.00		—		-66.67 *	3	-15	(minus outlier)

100-FOOT CONFIGURATION DISSOLVED METALS

Date Collected:	IN 11/17/91		IN 1/16/92		IN 1/23/92		IN 3/27/92		IN 4/17/92		IN 4/29/92	
Cu (mg/L)	0.006 *		0.002 *		0.001 *		< 0.001 *		0.002 *		0.002	
Pb (mg/L)	< 0.001 *		< 0.001 *		< 0.001 *		< 0.001 *		0.001 *		0.001 *	
Zn (mg/L)	0.003 *		0.003 *		< 0.002 *		0.42 U		0.034		0.019 *	
Al (mg/L)	< 0.01 *		< 0.01 *		0.2		0.04 *		< 0.01 *		0.02	
Fe (mg/L)	< 0.01 *		< 0.01 *		0.04 J		0.03 *		0.02 *		0.04 *	
	OUT		OUT		OUT		OUT		OUT		OUT	
Cu (mg/L)	0.008 *		0.001 *		< 0.001 *		< 0.001 *		0.002 *		0.002	
Pb (mg/L)	0.001 *		< 0.001 *		< 0.001 *		< 0.001 *		0.002 *		0.001 *	
Zn (mg/L)	0.014		0.002 *		< 0.002 *		0.24 U		0.031		0.023 *	
Al (mg/L)	< 0.01 *		< 0.01 *		0.18		0.04 *		< 0.01 *		0.02	
Fe (mg/L)	< 0.01 *		< 0.01 *		0.04 J		0.05 *		0.03 *		0.03 *	

Percent dissolved (Dissolved/Total) (INFLOW)													Average	
Cu (mg/L)	100.00 *		25.00		16.67		14.29		16.67		14.29		31	
Pb (mg/L)	> 50.00 *		5.26		25.00		7.69		2.44		5.56		16	
Zn (mg/L)	18.75		2.73		2.08		893.62		26.15		13.57		13	(minus outlier)
Al (mg/L)	> 5.88		0.38		15.38		2.35		0.31		0.77		4	
Fe (mg/L)	> 12.50		0.28		2.67		1.58		0.65		1.14		3	

Percent removal for dissolved metals											n Value	Avg	
Cu (mg/L)	-33 *		—		—		—		—		—	1	-33	
Pb (mg/L)	—		—		—		—		—		—	0	—	
Zn (mg/L)	-367 *		—		—		43 u		9		-21	4	0	
Al (mg/L)	—		—		10		0 *		—		—	2	5	
Fe (mg/L)	—		—		0 J		-67 *		—		—	2	-33	

*Value compute with one or both values < 5X Detection Limit
J = Value an estimate due to exceedance of QA
U = Data unuseable

of the project, both for the sampling and the laboratory analyses, and information related to accuracy of analysis for data validation. The sampling plan is also presented in Appendix E. Complete raw data are separately bound and available upon request.

Certain conventions were necessary to increase the precision of the performance data, since a portion of the data were at or near the detection level (DL). In determining performance of the swale in terms of percent removal, the following conventions were used:

- If both inflow and outflow concentrations were below the DL, no percent removal value was reported.
- If inflow concentrations were less than five times the DL and outflow concentrations were below the DL, no percent removal value was reported.
- If inflow concentrations were greater than five times the DL and outflow concentrations were below or less than five times the DL, percent removals were reported with a greater than (>) symbol in front of the calculated removal value.
- If both inflow and outflow concentrations were greater than five times the DL, percent removals are given as the value calculated as follows:

  [(Inflow - Outflow) / Inflow] * 100.

The number of observations used to calculate average percent removal is also shown on Tables 5-2, 5-3, and 5-4.

Total suspended solids. Total suspended solids (TSS) are an indicator of the aesthetic quality of water. In addition, solids carried in stormwater can have significant impacts in stream systems, where they can degrade the quality of spawning gravels, affect bottom-dwelling invertebrates, and fill pool and shoreline habitat. In lakes, solids can alter substrate characteristics, create deltas, and when suspended, reduce light penetration and increase murkiness in the water column. TSS data for the 200- and 100-foot swale configurations are illustrated in Figure 5-5 and Figure 5-6.

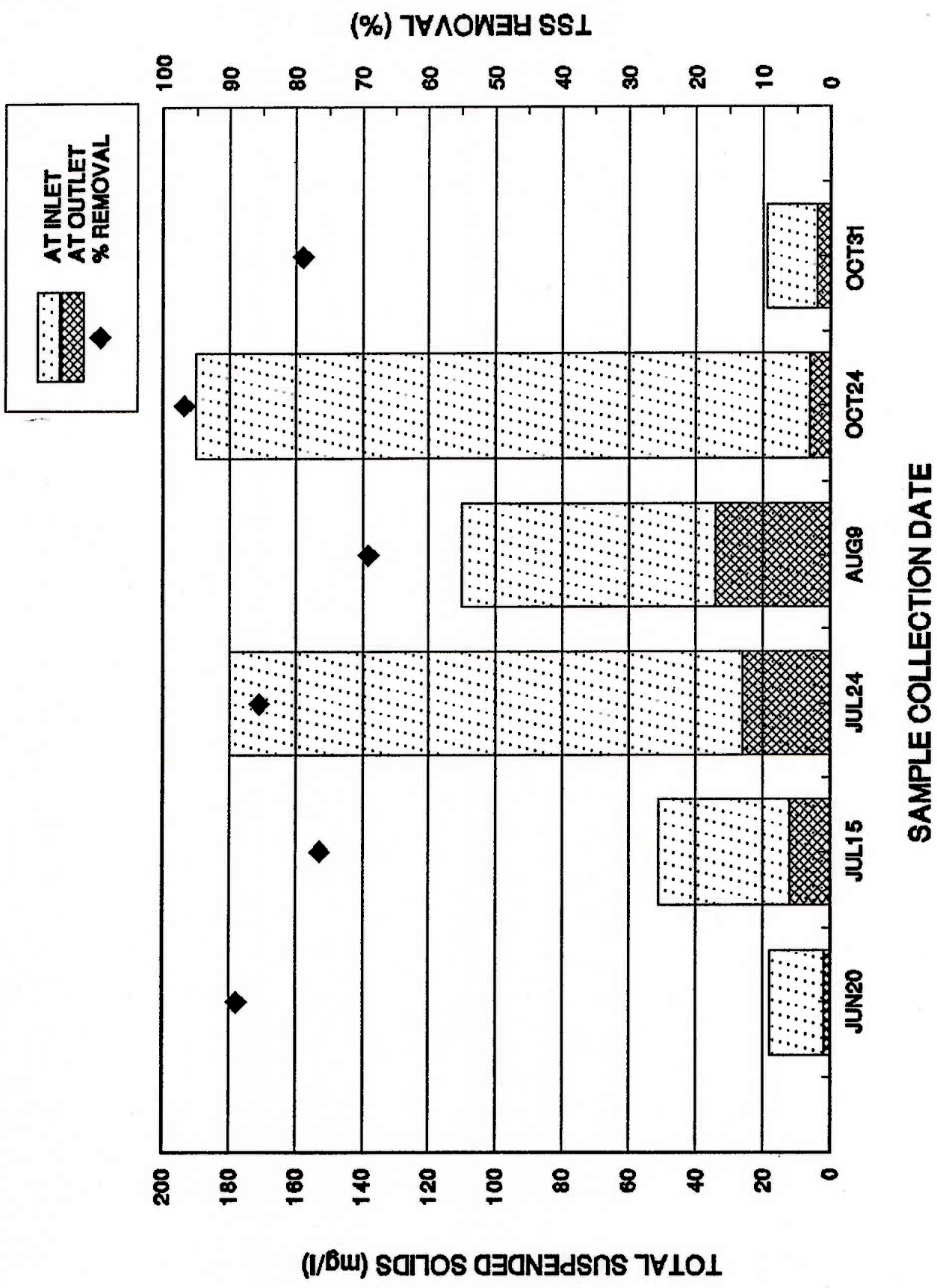

Figure 5-5. TSS Data, 200-Foot Length

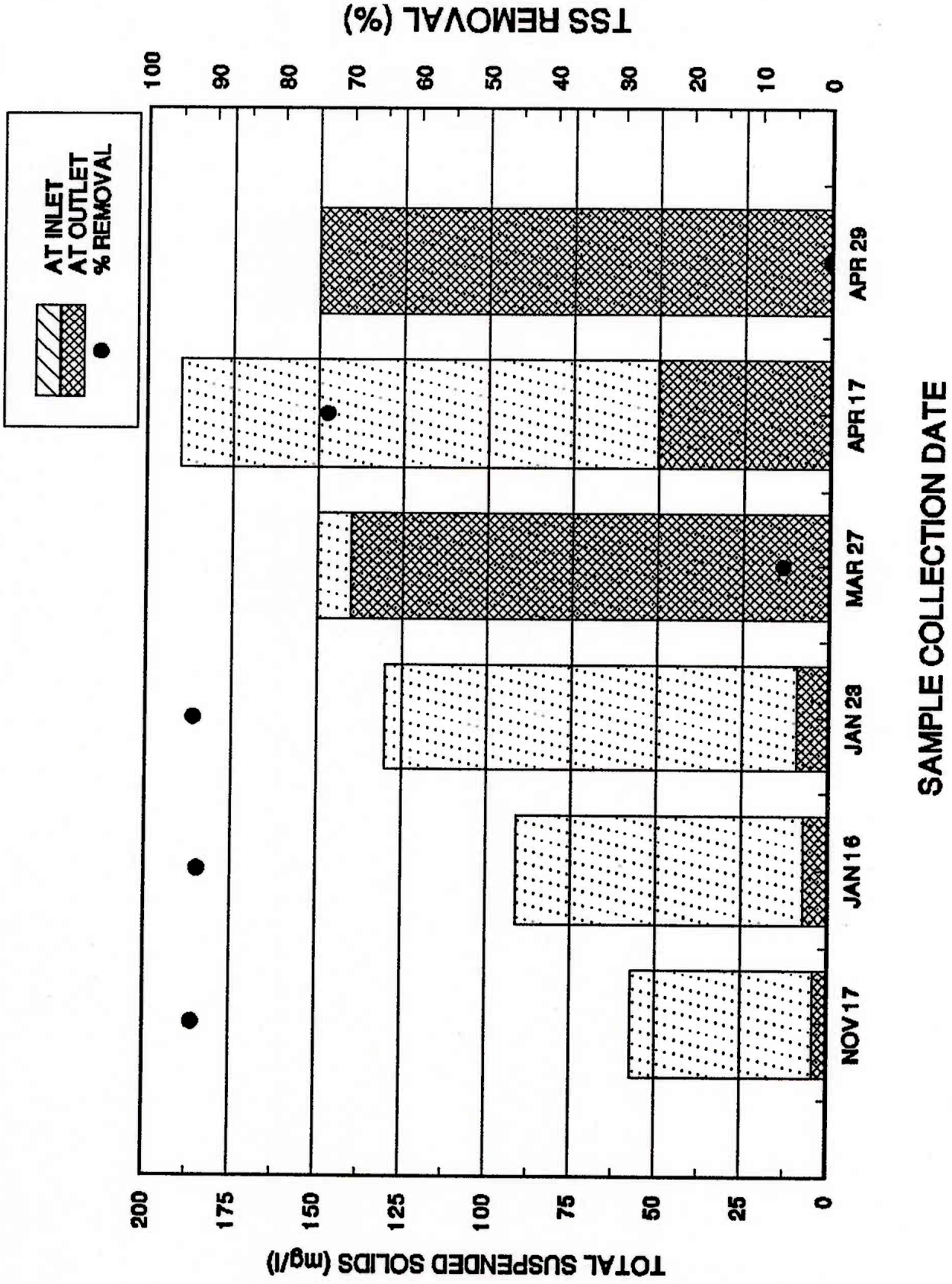

Figure 5-6. TSS Data, 100-Foot Length

For the 200-foot configuration, the range in TSS concentration at the inlet was between 18 and 190 mg/L, the average of the six storms being 95 mg/L. At the outlet the range was between 2 mg/L and 34 mg/L, with an average of 14 mg/L. TSS removal by the 200-foot long swale ranged between 69 percent and 97 percent, calculated on a per event basis. The average TSS removal for the six storm events was 83 percent (standard deviation [SD]=9 percent).

The 100-foot configuration showed a similar range of TSS concentrations at the inlet (57 to 190 mg/L), but outlet concentrations were higher, with a range of 4 to 150 mg/L. Removal rates were lower, with greater variability. The range was from 0 to 93 percent, with an average of 60 percent (SD=44 percent).

Turbidity. Turbidity is a measure of water clarity and is a major determinant of the water quality status of lakes and streams. It is measured in nephelometric turbidity units (NTUs), a measurement related to light scattering in a water column (American Public Health Association, 1985). State water quality standards require that turbidity not be increased by more than 5 NTU over background.

In urban stormwater runoff, turbidity is caused by suspended matter such as clay, silt, and finely divided organic and inorganic materials. Turbidity data for the 200- and 100-foot swale configurations are shown in Figures 5-7 and 5-8.

Average turbidity removal by both swale configurations is similar: 65 percent (SD=19 percent) for the 200-foot length and 60 percent (SD=19 percent) for the 100-foot length.

Oil and grease, total petroleum hydrocarbons. Stormwater runoff from urbanized watersheds contains variable amounts of oil and grease washed off roads, parking lots, and driveways. It is usually visible as a thin film or sheen. In addition to oil and grease, TPHs were analyzed. The TPH analysis is designed to identify that portion of the oil and grease of mineral or vegetable origin from those due to animal fats.

Because the oil and grease samples were collected after visual observation of a sheen, fewer data observations were available than for other constituents. Total oil and grease data for 200- and 100-foot swale configurations are indicated in Figure 5-9. Also included in this figure are data from storms collected April 3 and May 24, 1991 (200-foot configuration). Although a representative flow composite sample was not collected for these days, the grab samples for oil and grease were successfully collected.

Oil and grease concentrations for the two configurations were similar. Inlet concentrations ranged from about 40 mg/L to less than 2 mg/L, while outlet concentrations ranged from about 5 to less than 1 mg/L. The one very high value

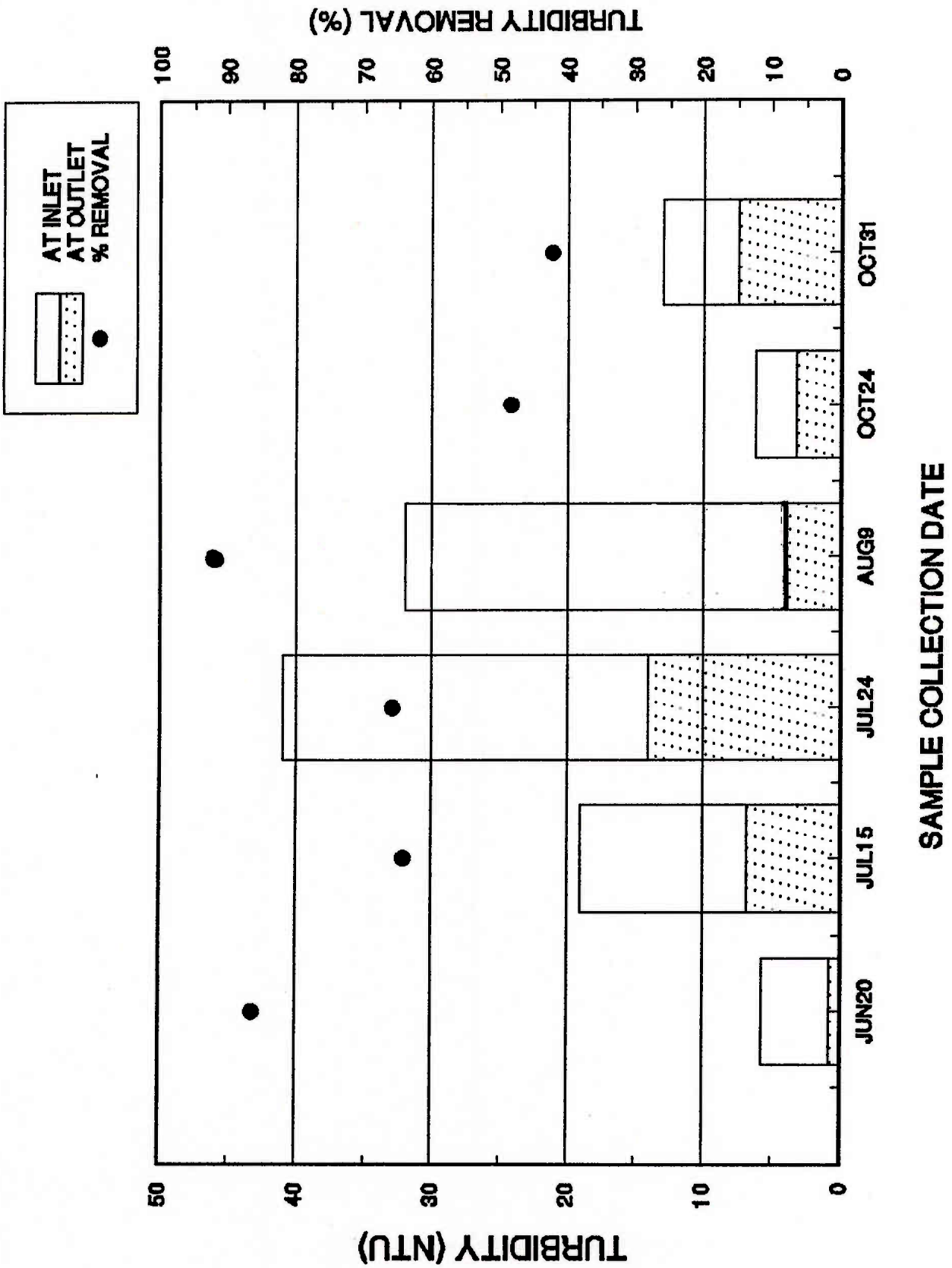

Figure 5-7. Tubidity Data, 200-Foot Length

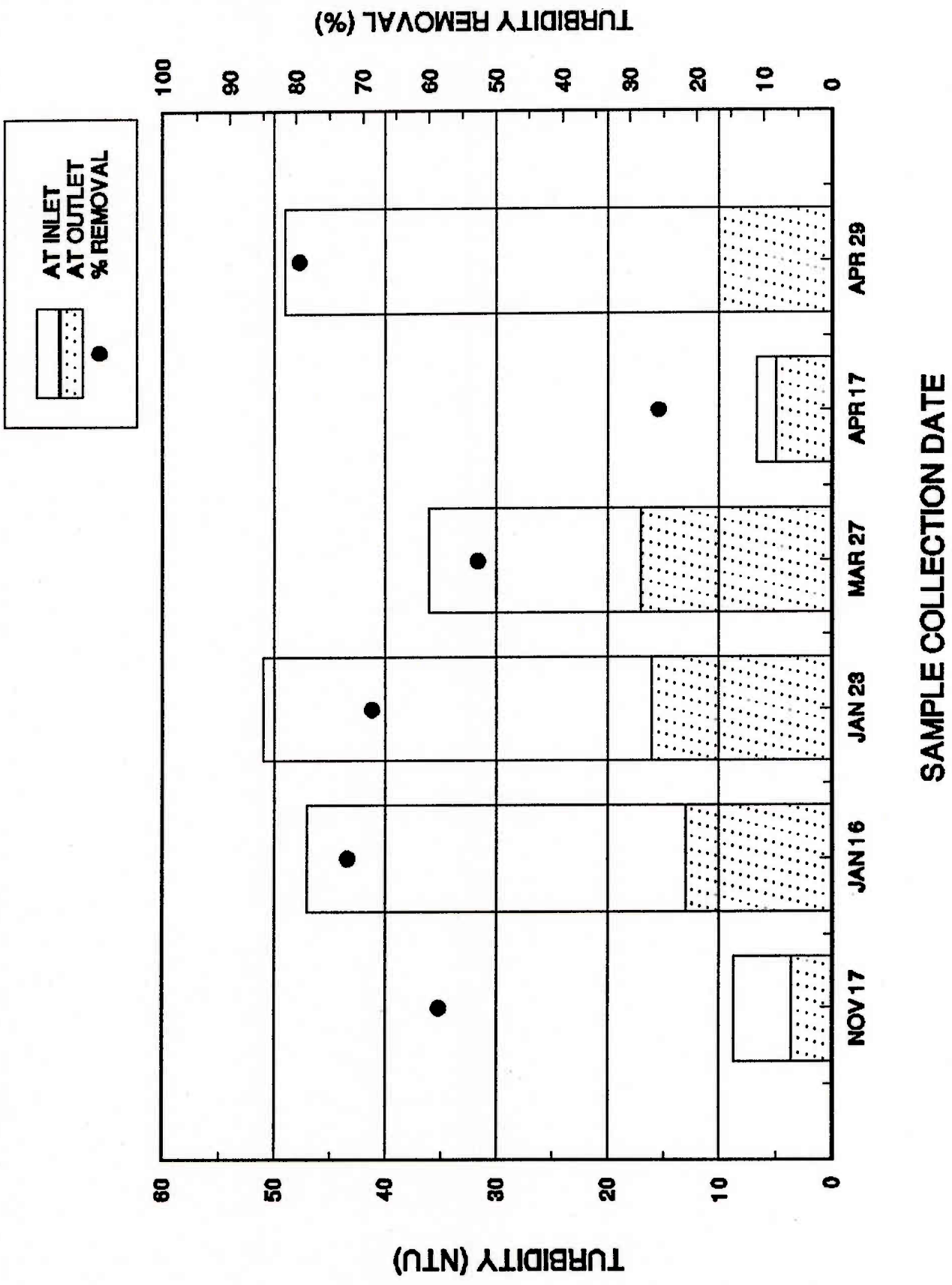

Figure 5-8. Tubidity Data, 100-Foot Length

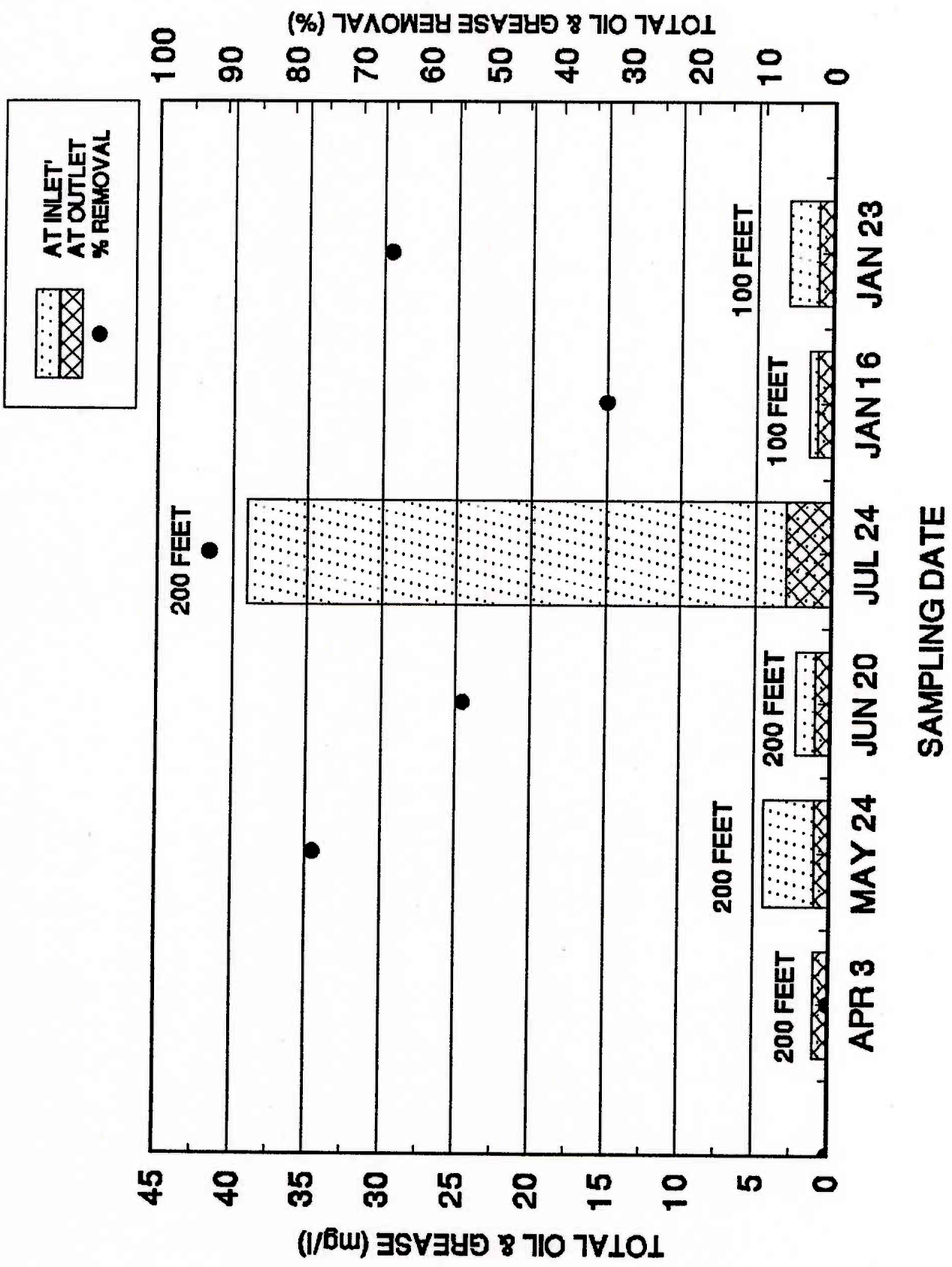

Figure 5-9. Oil and Grease Data, 200- and 100-Foot Lengths

from the October 31 storm is considered unreliable. Visual observations and notes recorded in the field for that date indicate only a slight sheen. This value was treated as an outlyer and not used to compute averages. Average oil and grease removal for the 200-foot swale length for the four storms with detectable sheens (including April 3 and May 24) was about 75 percent (SD=19 percent). TPH values were almost identical, with an average of 74 percent removal (SD=16 percent).

For the two storms from the 100-foot configuration, removals were greater than 49 percent for oil and grease values. TPH values were too close to detection levels to allow a meaningful estimate of removal.

Metals

Metals are a common pollutant in urban stormwater runoff. Metals can pose a threat to human health if ingested or inhaled, and are toxic to aquatic life, often at very low concentrations. For this study, three toxic metals (zinc, copper, and lead) as well as two indicator metals (iron and aluminum) were studied and will be discussed in this section. Samples were analyzed for both total and dissolved metals. Dissolved metals are defined as those passing through a 0.45 micron (μ) filter, and are generally believed to be readily available to aquatic life (Pat Davies, personal communication). Many researchers believe a portion of the particulate metal fraction is also biologically available (Bascombe, 1988, Morrison et al., 1984).

Zinc. Zinc in stormwater runoff may be contributed from several sources including deterioration of galvanized steel and from tire wear (Wigington, et al., 1986, Kulzer, 1991). The average total zinc concentration at the inlet for all twelve storms was 100 μg/L, with a range of between 16 μg/L and 250 μg/L. Figures 5-10 and 5-11 show total zinc data for 200-foot and 100-foot swale configurations.

The average total zinc removal, calculated on a storm by storm basis, was 63 percent (SD=15 percent) for the 200-foot configuration. The 100-foot swale configuration showed an average removal of 16 percent (SD=58 percent), and ranged from 86 percent to negative removals for two of the six storms.

Approximately 30 percent of the total zinc in the stormwater inflows, averaged over 11 storm events, was dissolved. Removal of the dissolved portion of the zinc averaged 30 percent for the 200-foot configuration, with only one event exhibiting negative removals. If this negative removal, which occurred August 9, 1991 during a storm with a high flow rate (1.35 cfs, see Table 5-1), is not included, the average dissolved zinc removal was 51 percent.

However, for the 100-foot swale, all storms exhibited negative removals of dissolved zinc (that is, more dissolved zinc was found in the outflow sample than in the inflow sample).

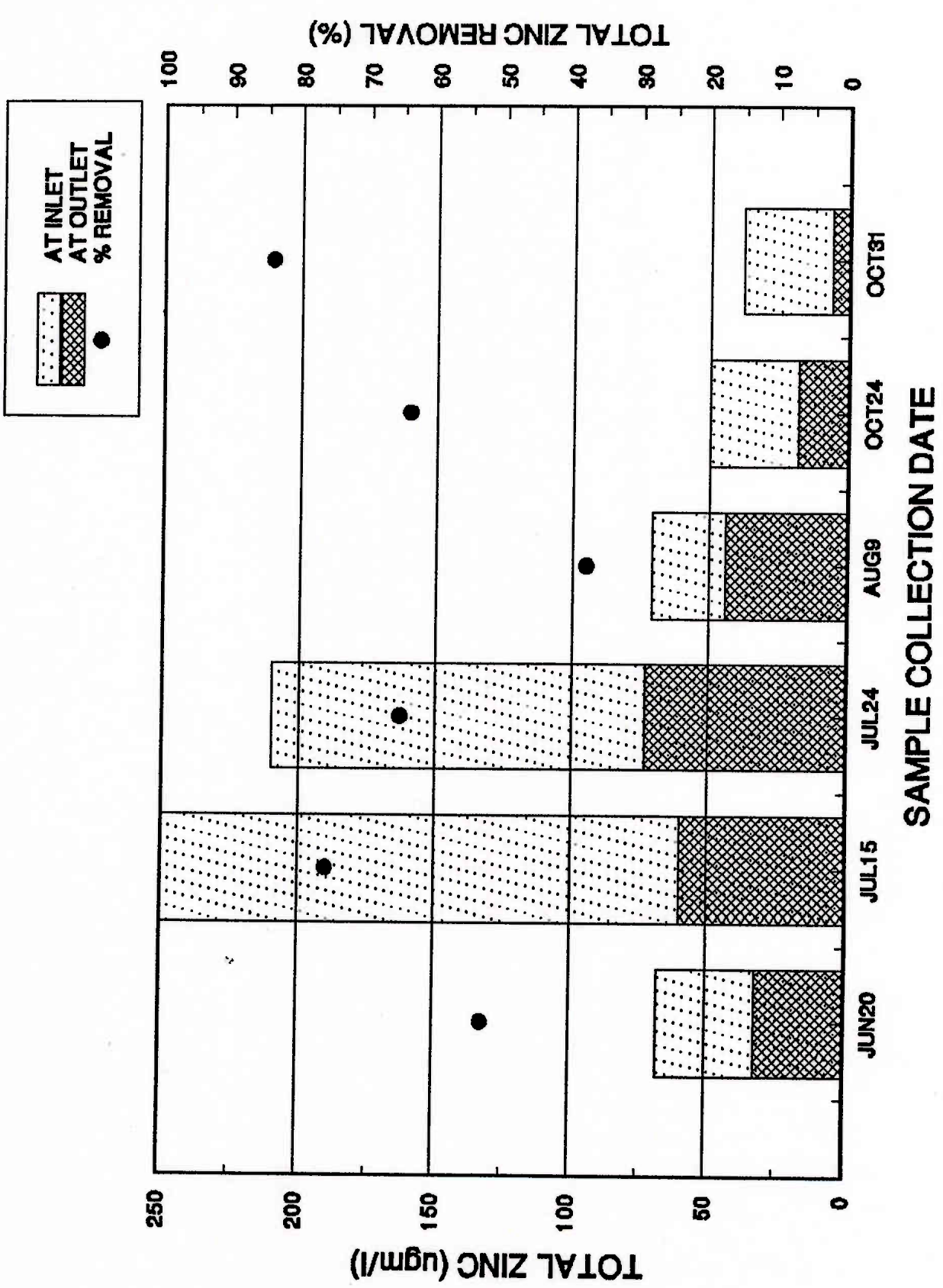

Figure 5-10. Total Zinc Data, 200-Foot Length

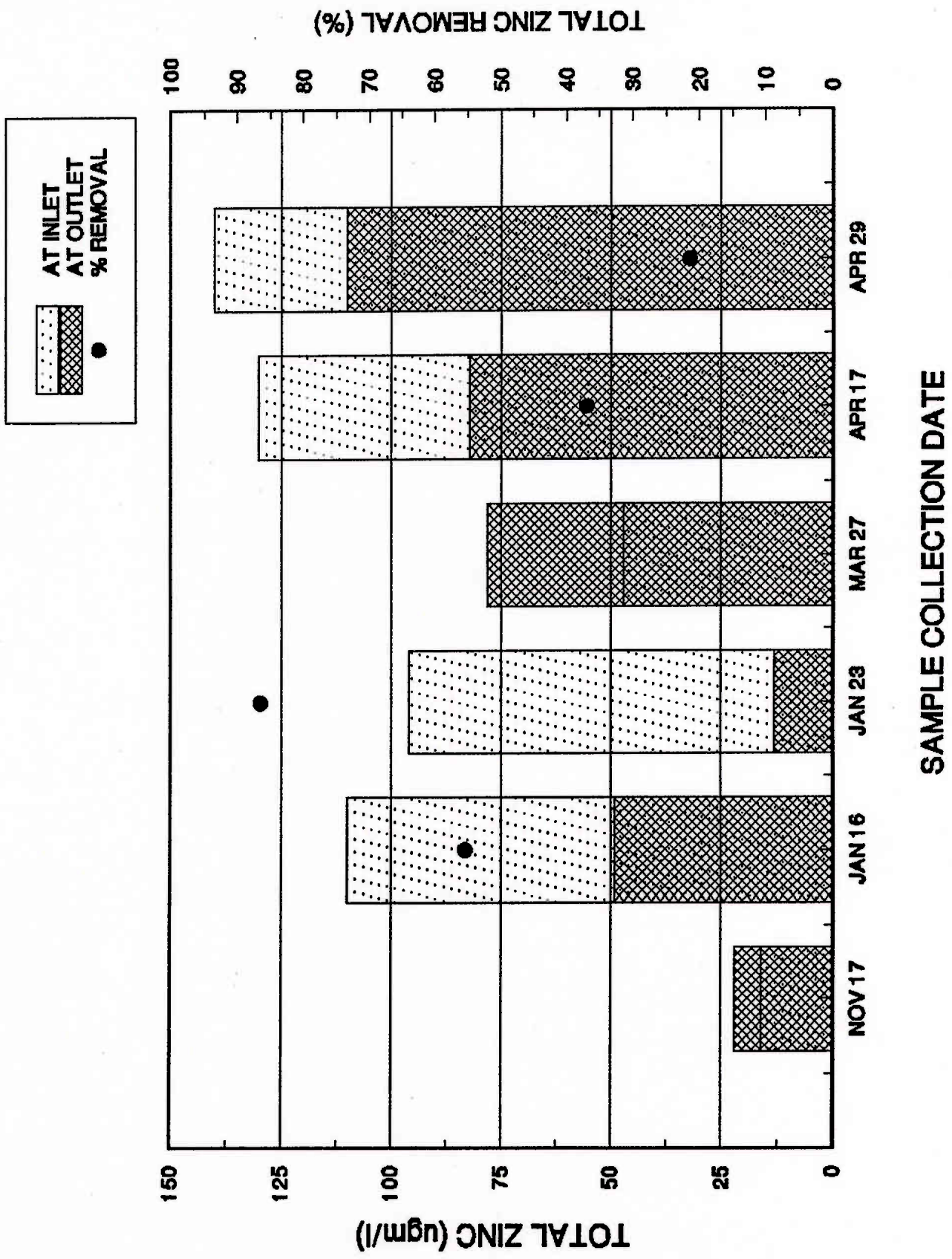

Figure 5-11. Total Zinc Data, 100-Foot Length

Copper. Copper concentrations were typically very low, often near the detection limit of 2 µg/L. For the nine storm events with copper levels above the detection limit (both configuration), the average total copper concentration at the inlet was 15 µg/L, with a range from 2 to 31 µg/L. Figure 5-12 shows the total copper data for 200- and 100-foot swale configurations.

Average copper removal for the 200-foot swale configuration, based on the two storm events above detection levels, was 46 percent (SD=15 percent). The range was 31 percent to 61 percent removal. For the 100-foot configuration, copper concentrations were higher, and all six storm events showed measurable amounts of copper. However, two of the events showed negative removals, and one showed no removal. The average copper removal for the six events was only 2 percent (SD=76 percent).

From the literature, copper was expected to occur mainly in the dissolved fraction. This was borne out by data from summer storms for the 200-foot configuration, which showed 82 percent of the detectable inlet copper concentration was dissolved for the three storm events collected. However, the winter storms collected for the 100-foot configuration did not bear out this expectation. An average of only 31 percent of the detectable copper was dissolved, based on inlet concentrations for six storm events. The combined average for all nine storms shows 56 percent of the detectable copper in dissolved form. Percent removal for dissolved copper was negative for both configurations.

Lead. Stormwater from urbanized watersheds contains variable amounts of lead, mainly from leaded gasoline and weathering lead-based paints. Inflow lead concentrations for both swale configurations averaged 13 µg/L for the eight events with detectable lead concentrations. Total lead data for 200- and 100-foot swale configurations are presented in Figure 5-13.

Lead tends to show a pronounced particulate character, hence good removals would be expected. However effects were partially masked by outflow concentrations being below the detection limit. From the data for the 200-foot configuration for three storm events with detectable lead levels, we know that lead removal was at least 67 percent (SD=17 percent). Storms for the 100-foot configuration showed much more variability, average removal being 15 percent (SD=91 percent).

Data for filtered samples showed that for the combined storm inflow samples, lead was less than 24 percent dissolved. Again, several values below the detection limit make generalization difficult. No removal of dissolved lead was seen at the 200-foot length, and negative removals were seen at the 100-foot length.

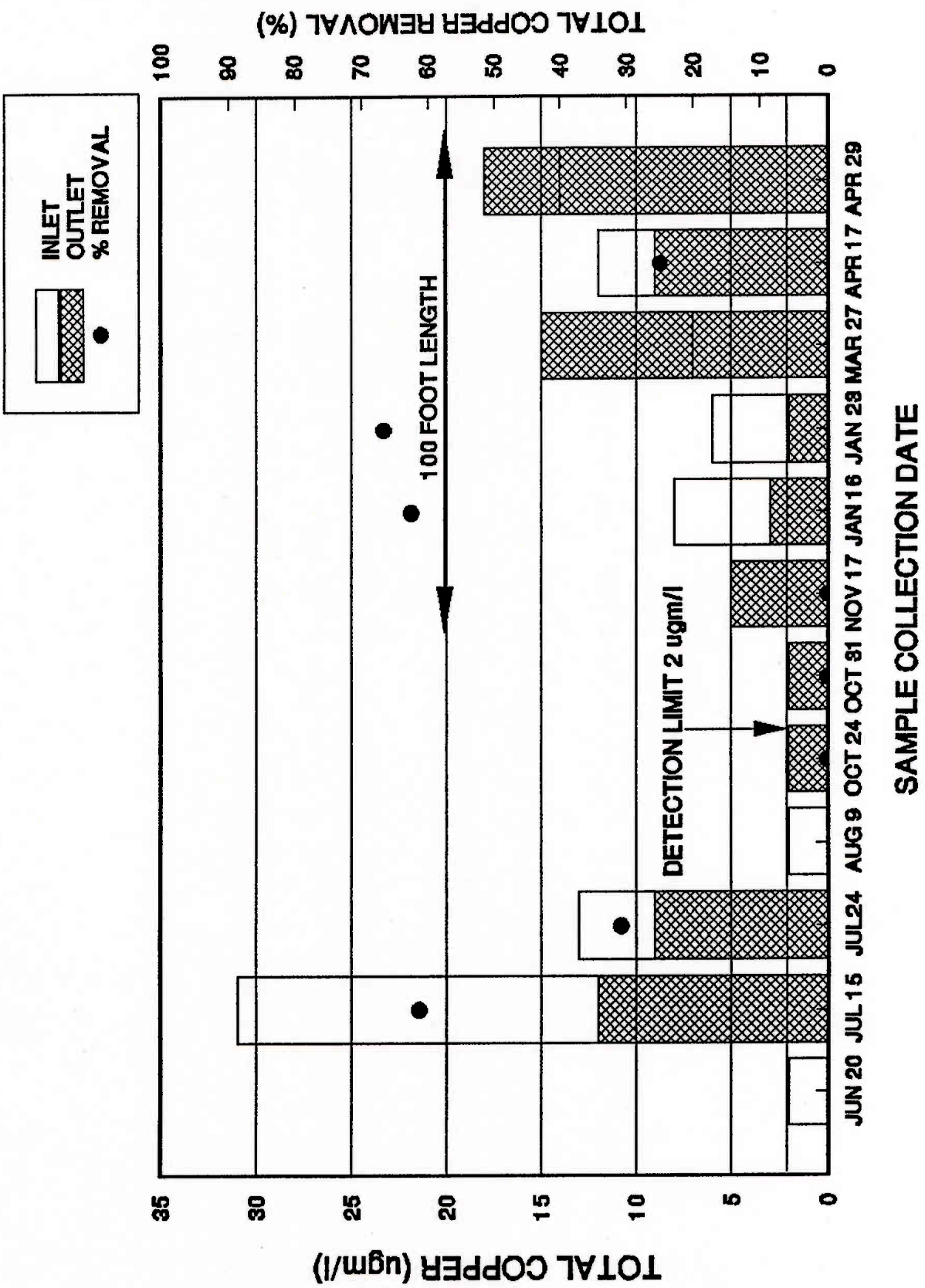

Figure 5-12. Total Copper Data, 200- and 100-Foot Lengths

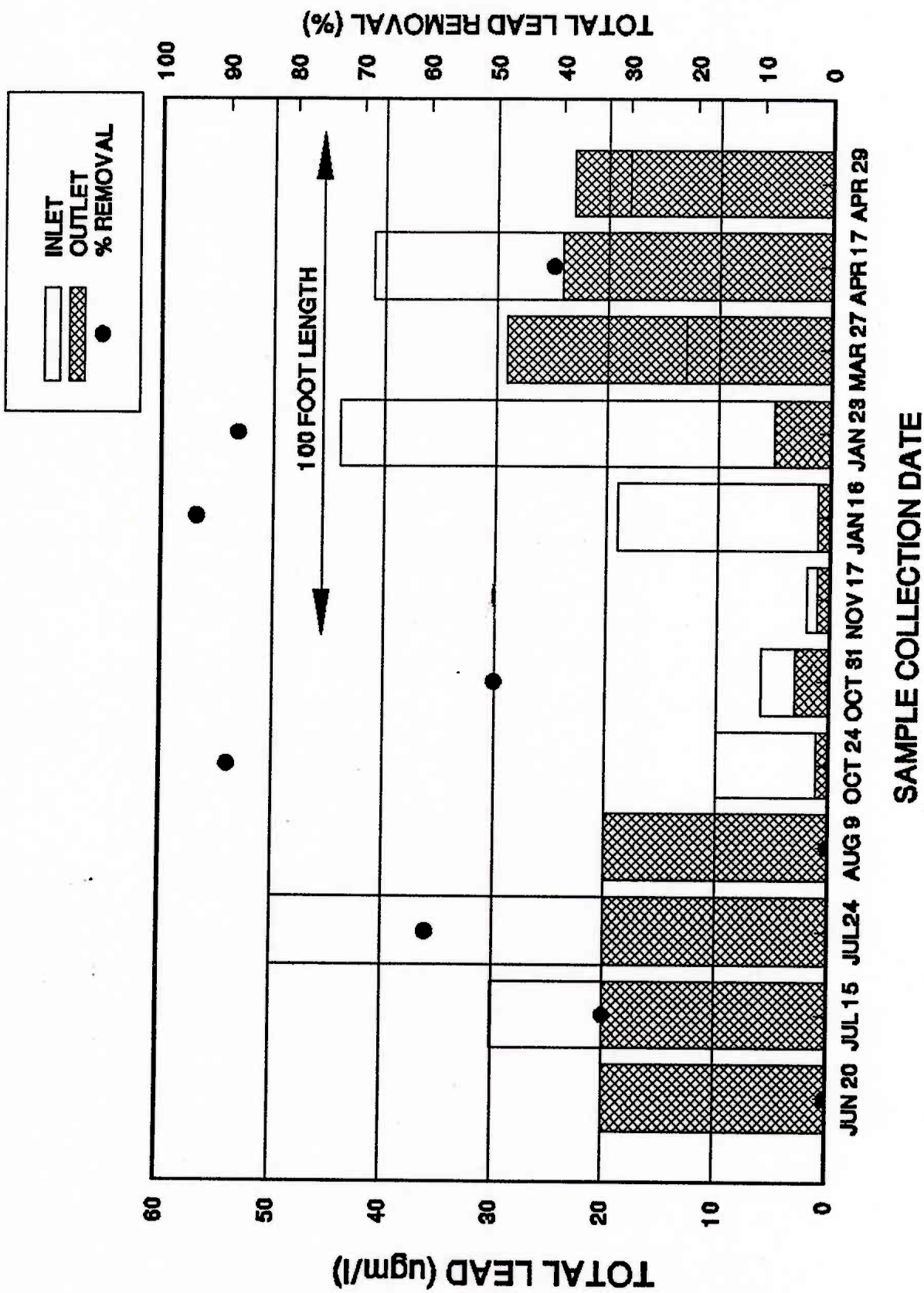

Figure 5-13. Total Lead Data, 200- and 100-Foot Lengths

Some additional insight into the likely behavior of lead (and copper) can be learned from analyzing the behavior of iron, which is present in stormwater in much higher amounts. Data for iron are discussed below.

Iron. Iron was analyzed in this study not so much as a primary source of concern, but because it might give better insight into the removal of other metals such as lead and copper which are a concern, but occur in very low concentrations in stormwater. Iron is the fourth most abundant element, by weight, in the earth's crust. Under exposed conditions ferrous iron is oxidized to the ferric state and may be hydrolyzed to form insoluble hydrated ferric oxide (American Public Health Association, 1985). These oxidation states may affect removal success by biofiltration. In general, particulate iron, which is formed by oxidation of iron-bearing groundwater, is not toxic to aquatic life. However, there is evidence that soluble iron, in concentrations above 1 mg/L, may be toxic to fish (USEPA, 1976).

It is not known whether the particle size distribution of iron would be equivalent to that of lead or copper, an element of uncertainty that must be considered in using the behavior of iron in swales to judge the behavior of lead or copper.

Iron was detected for all 12 storm events. The average inflow concentration of iron for all storm events averaged 1,730 µg/L (1.73 mg/L). Total iron data for 200-foot and 100-foot length swales are graphed in Figures 5-14 and 5-15.

Removal of iron was consistent for the 200-foot configuration, the average removal being 72 percent (SD=9 percent). Average removal for the 100-foot swale was, however, only 5 percent (SD=88 percent). This low removal value was because of two storms with large negative removals.

Dissolved iron constituted only 5 percent of the total iron concentration in the storms sampled. Negative removals for dissolved iron were seen for both swale configurations.

Aluminum. Aluminum is the third most abundant element of the earth's crust. It is commonly found in minerals, rocks, and clays (American Public Health Association, 1985). As was the case with iron, aluminum was monitored primarily to learn more about the behavior of the lighter toxic metals such as copper and chromium, which occur in very low concentration. There is evidence, however, that dissolved aluminum can affect fish growth, and can be toxic at levels of about 1 mg/L. Although toxicity seems to be related to pH, no clear trend has been determined. A national criteria of 87 µg/L for a 4-day average was set in 1988 (USEPA, 1988).

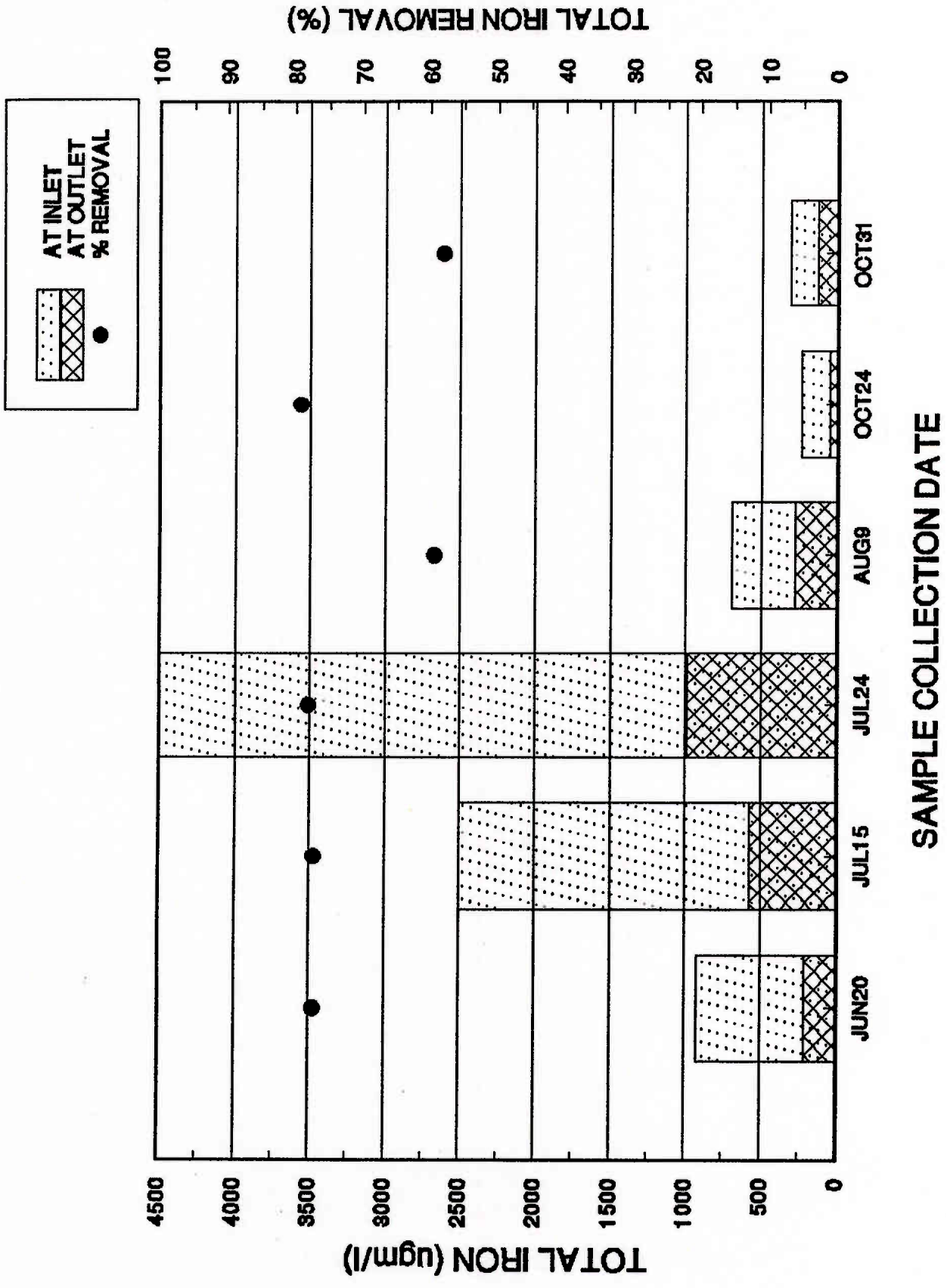

Figure 5-14. Total Iron Data, 200-Foot Length

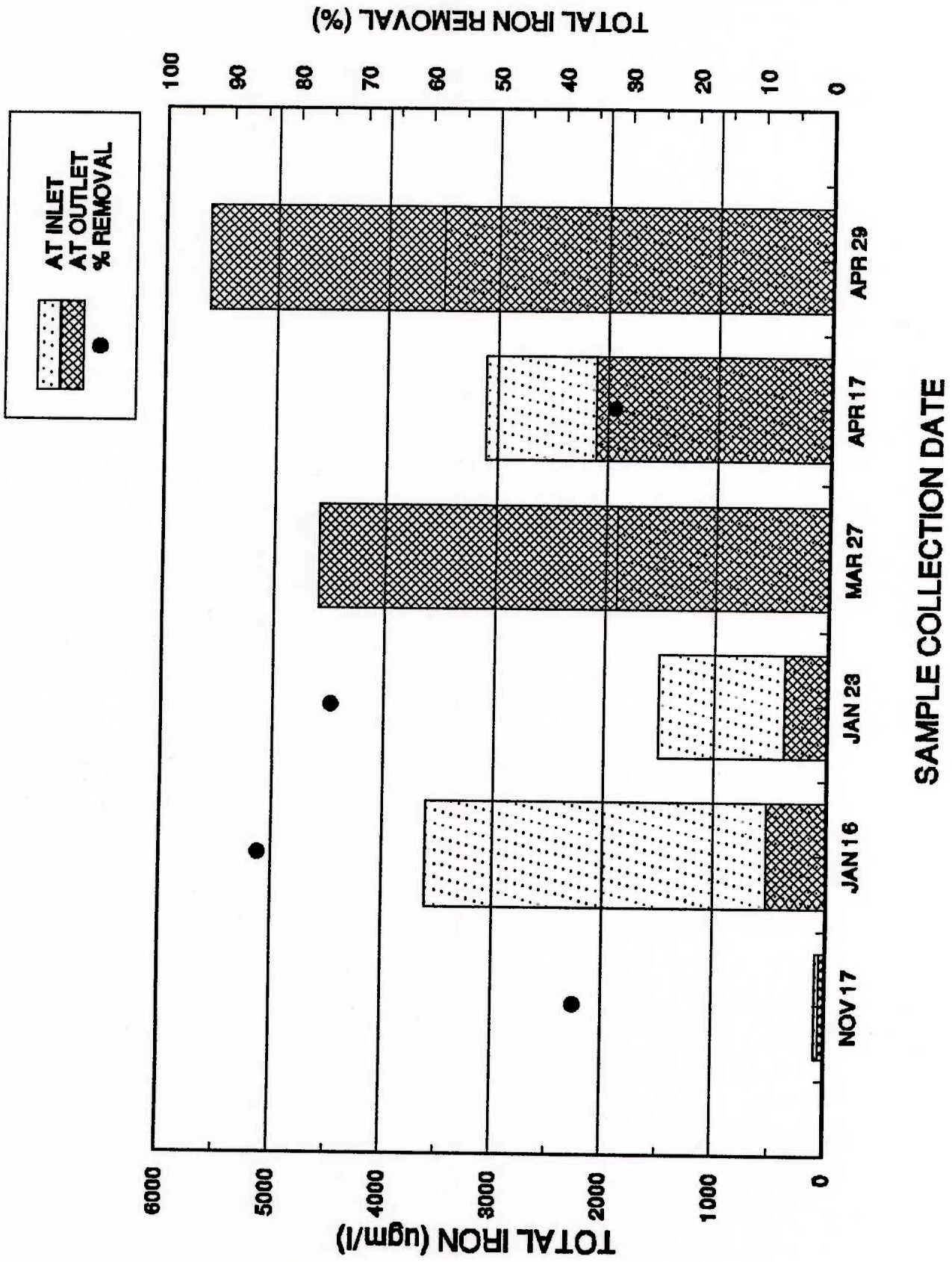

Figure 5-15. Total Iron Data, 100-Foot Length